BULLETIN OF THE RESEARCH COUNCIL OF ISRAEL

Section G GEO-SCIENCES

Bull. Res. Counc. of Israel. G. Geo-Sciences

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A CONIACIAN AMMONITE FROM THE SOUTHERN NEGEV (ISRAEL): *MUNIERICERAS LAPPARENTI* GROSSOUVRE VAR.

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During an expedition of the Geological Survey to the southern Negev in 1952, led by Messrs. Bentor and Vroman, a slab of grey limestone was picked up by the writer inside the mouth of Nahal Ya'alon (Wadi Bayan) that contained two impressions of an ammonite of the genus *Muniericeras* Grossouvre.

A peculiar faunal assemblage, found during this expedition in the southern Negev, has been recognised by the writer as of Coniacian age. In a note delivered by J. Vroman and the writer at the session of the Israel Geological Society on 5 April 1953, the following account was given of the Coniacian stage in the southern Negev.

The series of strata containing a fauna regarded as Coniacian consists of marl, chalk marl and marly limestone with some interstratified hard oolitic and detrital, mostly fossiliferous limestone beds. The base is a hard limestone, built from the shells of *Alectryonia dichotoma*. The top also forms a very hard oyster bed mainly of *Alectryonia dichotoma*. The whole section, about 50 m thick, is very uniform and abundantly fossiliferous. The fauna is also uniform throughout the whole section. Such fossils as *Al. dichotoma*, *Arca maresi*, *Hemiaster fourneli*, *Clypeopygus luynesi* and others appear repeatedly from the base to the top of the section. The series is readily distinguished from the underlying white Turonian limestone and from the white Santonian chalk above it by its yellow and grey colours and by its peculiar fauna.

This fauna contains numerous echinids as: *Leiocidaris subvenulosa* (Per. and Gauth.), *Thylechinus sadeki* (Fourtau), *Rachiosoma delamarrei* (Deshayes), *Rachiosoma majus* (Coquand), *Holectypus serialis* Deshayes, *Bothriopygus aegyptiacus* Fourtau, *Clypeopygus luynesi* (Cotteau), *Clypeopygus waltheri* (Gauthier), *Clypeopygus hierosolymitanus* (Blanckenh.), *Clypeopygus jullieni* (Coquand), *Pseudoholaster meslei* Gauthier, *Pseudoholaster moabiticus* (Blanckenhorn) and *Hemiaster fourneli* Deshayes.

The following Lamellibranchia could be identified: *Avicula gravida* Coquand, *Avicula atra* Coquand, *Cucullaea maresi* (Coquand), *Plicatula ferryi* Coquand, *Plicatula flattersi* Coquand, *Ostrea papieri* Thom. and Per., *Pycnodonta costei* (Coq.), *Alectryonia dichotoma* (Bayle) and *Pholadomya elliptica* Muenster.

From the badly-preserved Gastropods a few species are identified: *Natica gervaisi* Coq., *Globiconcha incerta* Thom. and Fer., *Pterodonta meslei* Thom. and Per., *Rostellaria bekariensis* Coq.

Many of these species are listed in the literature as Turonian, others as Santonian, whereas some are assigned sometimes to the Turonian and sometimes to the Lower Senonian. Only a few of them are noted specifically as Coniacian. In the southern Negev this fauna is contained in a series that forms a distinct morphological, lithological and faunal unit.

The Coniacian beds are preserved in the southern Negev to a wide extent. Their morphological appearance is due to: 1) their position between the hard Turonian and the soft Santonian rocks; 2) the alternation of hard and soft layers within the Coniacian section.

Where dips are slight, especially near the crests of anticlines, the Coniacian rocks are stripped down to the basal hard oyster-beds that form a cap 2–4 m thick above the white Turonian limestone. On the gently-dipping west flanks, subsequent wadis that cut their beds down into the hard layers separate several rows of low hills which are built from weaker layers and whose steep sides face the wadi bed. A hard layer on the top of the hills is gently inclined westwards and forms, at some distance, the substrate for the next subsequent wadi bed. On the steeply-dipping east flanks of monoclines, the hard Coniacian layers form a girdle of sharp hogbacks which preserve some weak layers between them. The Santonian chalky limestone and chalk (known in Northern Israel as *Texanites*-bearing Ka'akuleh limestone or chalk) appear at the feet of the decreasing hogbacks as a rolling plane. Beyond this strongly dissected plane rises, usually almost in synclinal position, Campanian chalk protected above by thick flint beds.

This simple pattern, which is well displayed in the Tsenifim (Sinaf) anticline, is varied by changing shapes of the folds and is often complicated by faults. Thus the Coniacian series is generally a well-recognisable feature in the landscape of the southern Negev.

A marly bed in the NE part of the Tsenifim (Sinaf) anticline contained numerous ammonites of the genus *Coilopoceras*. But there arose some doubt as to whether this bed, lying low in the section, near the base of the series, could be included in the base of the Coniacian stage. Thus the afore-mentioned *Muniericeras* was as yet the only ammonite found in the southernmost Negev in support of this analysis. It was only more than two years later that a *Barroisiceras* fauna, found in the central Negev, made it possible to establish definitely the occurrence of the Coniacian stage in the Negev.

It is therefore of special interest to note that recently Mr. Gevirzman, a student of geology, brought a fragment from Har Qatura (Jebel Qatar), some 10 km south of Nahal Ya'alon (Pal. grid 156/940). This ammonite is identical with the *Muniericeras* from Ya'alon. Its better state of preservation has enabled a more detailed examination and even a specific identification to be made.

The fragment, more than one-third of the last volution, consists of the body chamber with parts of the last septum behind. The last suture line, partly preserved, seems identical with the suture of *Ammonites gosavicus* v. Hauer (1, p. 13, Pl. 11, fig. 7–9). There are on the flank two lobes and one auxiliary lobe on the umbilical margin.

More recognisable are the details of three low, strongly-incised saddles on the flank, decreasing regularly towards the umbilic, and of a fourth saddle on the vertical umbilical wall. The flanks are flat and diverge from the narrow exterior region towards the region of the greatest thickness of the whorl on the umbilical margin. This results in an almost triangular whorl section.

On the rounded umbilical margin six strong tubercles are visible, giving about 16 tubercles for the whole volution. They are pointed, elongated and directed forwards. From these tubercles bifurcate flexuous ribs; some ribs are intercalated. From the ventrolateral nodes the ribs are strongly projected forwards. They weaken gradually in passing the fastigate ventral region and are only slightly recognisable when they reach the high and sharp siphonal keel, where they meet the opposite ribs in chevrons.

These characters point clearly to *Muniericeras lapparenti* Grossouvre (2, p. 158, Pl. XXIX, fig. 1 and fig. 5; Pl. XXXV, fig. 3). The specimen from the Negev differs from the typical *M. lapparenti* (ibid, Pl. XXIX, fig. 1) by the greater number of its umbilical tubercles (about double), by its more flexuous, less numerous and more widely-spaced ribs, non-bifurcating on the ventrolateral periphery, and by its more triangular whorl section.

The three figures given by Grossouvre are distinctly different from each other. This seems to indicate that *M. lapparenti* is a very variable species. The specimen from the Toucas collection (ibid, Pl. XXXV, fig. 3) shows less numerous, more spaced and more flexuous ribs, that do not bifurcate at the external periphery. Its umbilical tubercles are pointed, but their number is only about 8 for the volution.

Muniericeras rennense Grossouvre (2, p. 160, Pl. XXVX, fig. 2) has flat dense ribs that fade out before reaching the keel, which is therefore not cordate.

Muniericeras inconstans Grossouvre (2, p. 159, Pl. XXXV, figs. 4–5) has more flexuous ribs than the Negev specimen, but it has no umbilical tubercles.

Muniericeras gosavicus (v. Hauer) (1, p. 13, Pl. 11, figs. 7–9) has numerous umbilical tubercles, although still less than the ammonite from the Negev. The suture line seems to be identical in both ammonites, but *M. gosavicus* has a flattened venter and an elliptical whorl section.

We arrive therefore at the conclusion that the ammonite from the southern Negev is a variety of *Muniericeras lapparenti* Grossouvre, but distinguished from it by (1) its double number of umbilical tubercles, (2) its less numerous ribs, and (3) its more triangular whorl section. The nodes at the meeting point of the opposite ribs are weaker and the keel is therefore more feebly crenulate.

The specimen from Har Qatura apparently was damaged during the life of the ammonite. For from a swollen but completely healed fracture line, the last part

of the left flank is strongly inclined inwards. The shell, although deformed, tends to preserve its triangular whorl section.

STRATIGRAPHICAL REMARKS

The ammonites from Ya'alon and Qatura are derived from a grey limestone with numerous, partly-silicified limestone concretions. This limestone and the underlying marly layers are bounded by Turonian limestone below and Santonian chalk above. From Har Qatura the writer has collected (1952): *Cucullaea maresi, Alectryoma dichotoma, Clypeopygus luynesi,* fragments of *Leiocidaris subvenulosa* and other fossils of this series.

The Coniacian section in the Negev shows immediately above the first hard oyster-beds with *Alectryoma dichotoma,* capping the Turonian limestone, yellow marly layers with *Coilopoceras,* some very close to *C. colleti* Hyatt. The chalk marls near the base contain also *Hemitissotia galeppei* Pervinq. The following higher beds, with an abundant Echinid and Pelecypod fauna, bear various Barroisiceratidae, as: *Reesidoceras gallicum* (Grossouvre), *Forresteria allaudi* (B. L. T.) and others. The top layers, capping the higher marls, consist mainly of hard grey oyster beds with limonitised and partly silicified fossils.

From the position of the grey limestone of Ya'alon and Qatura that yielded *Muniericeras lapparenti* Grossouvre var. it may be concluded that this bed belongs to the upper part of the Coniacian section of the Negev.

Dimensions of the specimen from Har Qatura:

Length of the fragment	100 mm
Diameter	nearly 100 mm
Maximum height of the whorl	42 mm
Maximum thickness of the whorl	about 22 mm
Umbilic	about 25 mm

ACKNOWLEDGEMENTS

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Figure 1

a-e: *Muniericeras lapparenti* Grossouvre var. from Har Qatura, southern Negev, Upper Coniacian.

a. View of left flank; note distorted upper part and the remains of the suture line. The ends of the lobes are all broken, and some details of the saddles are damaged and distorted, but as a whole the saddles could be traced in the main lines with sufficient accuracy. Nat. size
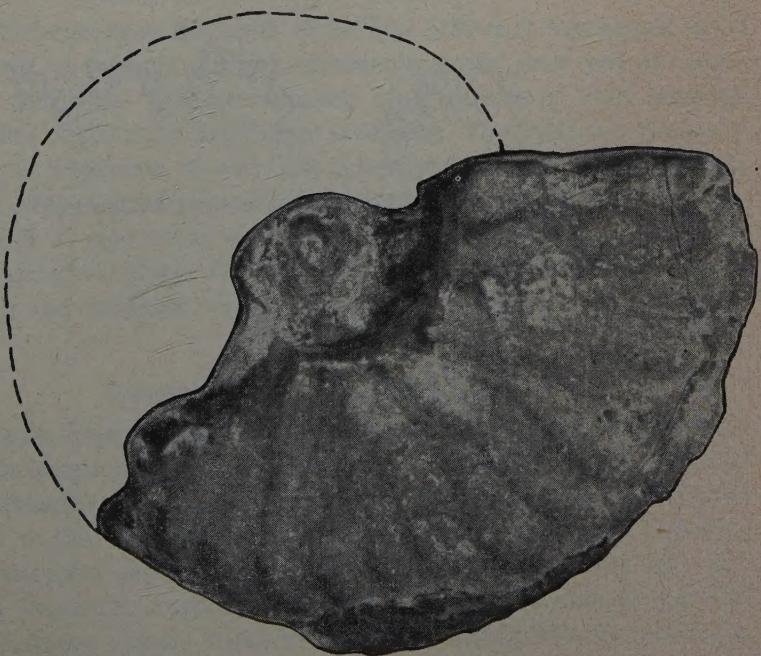
b. View of right side. Nat. size

Figure 1 (continued)

c.　Ventral view. Note the swollen part on the upper right. The inclined part is not visible. Nat. size
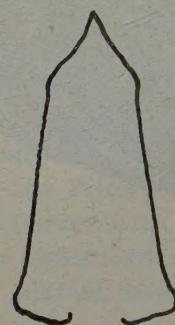
d.　Whorl section taken behind the fracture, shows a slight asymmetry. Nat. size
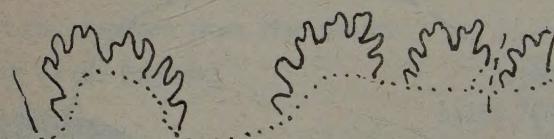
e.　Suture line. Dotted lines indicate broken parts. Enlarged × 2

TRIASSIC IN THE DEEP BORING AT KFAR YERUHAM (REKHME), NORTHERN NEGEV, ISRAEL

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During the last five years, numerous deep oil borings were carried out in Israel. In May 1955 the author of this paper examined, on behalf of the Geological Survey of Israel, a part of the samples of the boring at Kfar Yeruham (Rekhme) from the depths ranging from 2217 to 2760 m; this boring is situated approx. 30 km south of Beersheva and 40 km north of the Ramon anticline, the core of which is formed by Triassic. The boring was executed on behalf of the Husky Oil Co., which kindly permitted the publication of the results of this examination.

GENERAL REMARKS ON THE SAMPLES

The 543 m rock thickness from the depth of 2217 to 2760 m is represented by 34 samples; they consist of cuttings of black bituminous-pyritic shale and of coarse, granulous detritic limestone. The intermingling of fragments of both materials prevented recognition of the exact lithological succession. The fossils are present in the cuttings mostly as fragments, so that their determination is very difficult and in most cases can be neither exact nor certain. Nevertheless, with the help of these fossils it was possible to reconstruct a reasonable stratigraphical succession. They are tentatively recognised as: Upper Triassic (Carnian?), well-proved Middle Triassic (Anisian-Ladinian?) and supposed Upper Werfenian.

PALAEONTOLOGICAL ANALYSIS

The first three samples, from 2217 to 2235 m, do not contain any useful palaeontological remnants: the small fragments of some gastropods and pelecypods are rather insignificant. The material of the samples from the 2235–2576 m depth is lithologically very similar to that of the samples above. It contains fragments belonging possibly to the pelecypod genus *Halobia*. In some of these samples and also deeper, many rock fragments contain numerous remnants which possibly represent algae of the *Diplopora*-type usually found in Upper and Middle Triassic sediments; because of pyritisation of these remnants, no microscopic examination and no exact determination were possible.

In the 2600–2609 m sample a gastropod, resembling the genus *Hologyra*, was tentatively determined. In the 2609 m sample, *Entolium torquata* Schl. was recognised, indicating Lower Muschelkalk. In the sample from the 2650 m depth, a tiny inner whorl of the ammonitic genus *Beneckeia* (possibly *B. wogauana*) indicates undoubtedly lowermost Muschelkalk age. In the same material are present other fossils, such as *Myophoria elegans* or *postera* and *Dielasma ecki*, giving evidence of the same age. In deeper samples occur several other species of *Myophoria* (*?ovata, ?orbicularis, ?intermedia, ?blakei*), *Cidaris* (*?subnodosa*), *Pecten* (*?schroeteri*) and other fragmentary fossils; in the sample from the depth of 2730 m a small crinoid-columnal resembling *Encrinus* was detected.

CONCLUSIONS

In spite of the badly-preserved material, several fossils of indicative value were determined which definitely prove the Triassic age. The *Beneckeia* fragments, found at the 2650 m depth, serve as the starting point, being of well-defined lowermost Mu-
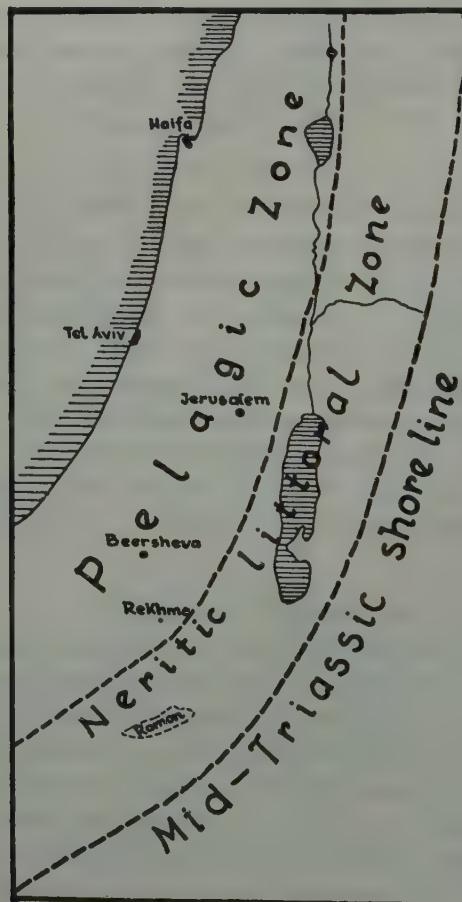

Figure 1
Palaeogeography of Middle
Triassic in Palestine

schelkalk age. It is therefore probable that a part of the samples, representing 110 m thick layers below the sample with Beneckeia, already belongs to Upper Werfenian. Also it is possible that at least a part of the material which contains *Halobia*-like fragments and the supposed "Diplopora", is of Upper Triassic (Carnian) age. We may tentatively suppose that of the whole 543 m thickness of the Triassic, the lowermost 30 m are of Werfenian age, some 400 m of Mid-Triassic and the remaining 100 m of Upper Triassic age.

Of great interest are the differences in facies character between the Triassic series exposed in the Ramon anticline and the Triassic of the above-discussed boring at Kfar Yeruham (Rekhme). The first one is entirely of epicontinental character, germanotype in its sedimentary style, being composed of a continental lower part, an epicontinental sandy-calcareous middle part (Muschelkalk or Anisian-Ladinian) and a lagunal gypsiferous upper part. Most of the Kfar Yeruham Triassic is rather of deep sea origin. This fact implies longer durability and relative stability of marine sedimentation in this area. As assumed above, the marine sedimentation probably began already in the Werfenian and continued at least in the beginning of the Upper Triassic (Carnian).

Thus, approximately 30 km to the west or west-northwest of the epicontinental Ramon zone the deep pelagic zone of the Triassic began; this zone continued as far as Anatolia and Aegeis.

It is therefore not excluded that in the Rekhme area, or not very far west of it, marine Lower Triassic sediments repose in continuation on marine Permian sediments similar to those of the Kyrenia range in Cyprus, or to those—recently described by R. G. S. Hudson (1958)—of Kurdistan in Iraq.

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GEOCHEMISTRY OF WATERS IN NORTHERN AND CENTRAL ISRAEL AND THE ORIGIN OF THEIR SALTS

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ABSTRACT

The salt content of the ground waters in the Pleistocene formations of Israel's coastal plain is of cyclic origin (salt spray and rain water). The composition of the chloride salts is almost identical with that of sea water, conditioned by cation exchange in the layers percolated.

The mechanism of exchange is elucidated by statistical material based on the "alkali number" $(Na^+ + K^+)/Cl^-$ ratio).

The changes of the original alkali number of sea water are conditioned by the equivalent $(Ca^{++} + Mg^{++})/(Na^+ + K^+)$ ratio. This relation in practice depends on the chloride concentration of each ground water. The alkali number generally increases at lower and decreases at higher concentrations of Cl^- and depends also on the nature and the quantity of the exchange material, which differs from one geological formation to the other.

Ca^{++} and Mg^{++} ions are for the greater part present as bicarbonates, whose solubility product increases with the quantity of chlorides, as well as with temperature.

Cyclic salts from sea water transported by rain and spray lose on the average 18 percent of their K^+ content in the central part of the coastal plain in relation to Na^+ until reaching the ground water.

The Cl^-/SO_4^{--} ratio in the central and northern part of the coastal plain is very close to that of sea water. The quantities of "non-cyclic" SO_4^{--} may be assumed to derive from industrial influences. The higher concentrations of sulphates in the South and the Lydda area (Ras el Ein Springs) are caused by the influence of the more arid climate. The same holds true for the increase of total salinity from north to south, which for equal conditions depends on the precipitation, moisture factor and rate of infiltration.

Highly saline waters in limestone formations (above 500 mg Cl^- per l.), as in Haifa Bay and on the western slope of Mt. Carmel, are derived from inundations of the sea over the unprotected limestone basement during the last geological period. Cl^-/Br^- ratios are here mostly very close to that of sea water, as is often true also of the Na^+/K^+ ratio.

The Cl^-/Br^- and Cl^-/SO_4^{--} ratios in all major springs and ground waters of the coastal plain and of the Cenomanian-Turonian water table is very similar to that of sea water, thus excluding the existence of major quantities of evaporates.

Waters with low Cl^-/Br^- ratios (Br^- concentration above normal) are represented by the springs around Lake Tiberias and the Beisan Springs, most of the smaller springs from the perched water table of Senonian and Eocene marls, and the waters of several wells in Cenomanian limestone in the Jezreel Valley.

An attempt is made to prove that the large salty springs draining into the Jordan depression are derived from marine solutions which have lost the greater part of their NaCl by precipitation. By comparing the "alkali number" with the Cl^-/Br^- and the Na^+/K^+ ratios a striking similarity to an evaporated marine brine is evident. The residual solution, after a partial precipitation of common salt was trapped, probably in sandstone formations,

and/or spread out by eastern winds and percolated underground, while the underlying salt deposits are beneath the underground drainage level of Lake Tiberias or further south in the Jordan graben.

Finally, by comparing the waters of the Dead Sea with its main salt supply from Lake Tiberias and the Beisan Springs, the quantitative differences in their composition (decrease of ratios Cl^-/Br^-, Na^+/K^+, Ca^{++}/Mg^{++}) are explained by the elimination of gypsum and NaCl through precipitation.

INTRODUCTION

In 1928, an attempt was made to analyse qualitatively the composition of the Dead Sea waters and to investigate the problem of ground water salinity (Loewengart 1928). Since then a considerable amount of data has been collected. In the present paper an attempt is made to describe the geochemistry of the waters in Northern and Central Israel and to determine the origin of their salts by analysing the data available.*

Although the material is incomplete, an attempt has been made to arrive at certain conclusions which may be of practical geological importance.

A complete analysis should, of course, consider the four most important cations, Na^+, Mg^{++}, Ca^{++}, K^+ and the three most important anions: Cl^-, SO_4^{--}, and CO_3^{--} The material at my disposal included very little on the Ca^{++}/Mg^{++} ratio, both elements being taken together as general hardness, and not very much on SO_4^{--}. But it included data on the Cl^-/Br^- ratio, which made possible an analysis of the origin of the ground water and of its geological history.

SOLUBLE COMPONENTS OF GROUND WATERS AND THEIR ORIGIN

The components of ground waters may be outlined as follows:

1. Salts of sea water of recent and fossil origin (chlorides and sulfates).

   a. Salts which are transported inland by air ("cyclic-salt") and, to a lesser degree, by infiltration.

   b. Connate salts contained in fossil waters of aquifers as well as of aquicludes.

   c. Salts which have been differentiated by base exchange, evaporation and renewed dissolution.

2. Carbonates—practically absent from sea water. The cations are derived from the dissolution of the ever-present Ca^{++}-Mg^{++} carbonates in our rocks.

As this paper deals first and foremost with the origin of the sea salts in the water, the carbonates are not treated as they would deserve in view of their general importance. Their presence does not require much explanation.

The percentage composition of sea water in equivalents is:

	%		%
Cl^- and Br^-	45.14	Na^+	38.68
SO_4^{--}	4.68	Mg^{++}	8.82
CO_3^{--}	0.18	Ca^{++}	1.68
		K^+	0.82

Thus 90 % of the combined salts are halogens and 88 % of these are alkali chlorides. The ratio $100(Na^+ + K^+)/Cl^-$ will henceforth be called the "alkali number" and used as an index of the changes the salts of sea water have undergone in ground water.

In giving ratios between different elements, we had to be guided by the existing literature, which prefers to give certain ratios in absolute weights (i.e., the ratios Cl^-/Br^-, Na^+/K^+ and Cl^-/SO_4^{--}). On the other hand the "alkali number" and the $(Ca^{++} + Mg^{++})/(Na^+ + K^+)$ ratio are expressed in equivalents. This procedure with all its drawbacks is still the best way to make comparisons with the pertinent literature.

The air-borne transport of sea salts in the form of finely dispersed dust and drops of sea water with or without the influence of rain is quantitatively important (Conway 1942, Rankama and Sahama 1950, p. 314, quoting Jacobs). Conway (1942) also made a theoretical calculation of the landward transport of sea salts on a global basis which deals quantitatively with this important phenomenon. During air-borne transport, the quantitative composition of sea water remains fairly stable except for the addition of amounts of soluble components (mostly carbonates) of terrestrial origin and of industrial products, the most important being sulphuric acid. In Israel, for instance, one million tons of mineral oil containing an average of 1.5 per cent of sulphur are used and refined annually. Thus about 45,000 tons of H_2SO_4 are blown into the air. If we consider the total annual drainage of the ground water to be some 1000 million m³ per year, and if only 10 per cent of the air-borne sulphuric acid reaches the ground water, then we will already enrich the SO_4^{--} content of the ground water by about 4 mg/1. Similar but much smaller human influences are due to fertilisers containing SO_4^{--}, NO_3^-, and K^+.

With the infiltration of the water into the ground, the sea water undergoes base exchange. The proportions of the cations change, while the halogen anions pass through unaffected.

The interchange of ions between the stagnant waters of the aquicludes and those of the slowly flowing waters in the aquifers takes place very slowly but must have brought about a change in the material equilibrium during geological time.

When percolating through layers which contain materials capable of absorbing and releasing cations—this being the case to a certain degree in practically all formations—the four important cations, Na^+, K^+ (the alkalis), Ca^{++}, Mg^{++} (the alkaline earths), are absorbed and released in varying proportions.

While the rate of absorption is strongest with Ca^{++}, decreasing with Mg^{++}, K^+ and Na^+, the final result in nature depends on the mass action of the cations in the percolating solution upon the cations of the absorbing colloids. In this process we may regard the alkalis as one unit, the earth alkalis as another. If alkalis, expressed in equivalents, are superior in quantity, a large number of them is retained by the colloids, setting free Ca^{++} and Mg^{++}. The quantity of the latter, therefore, increases in ground water, and this process takes place with greater intensity as the salinity of the water is increased.

If, however, Ca^{++} and Mg^{++} are more abundant, as is the case with increasing hardness and decreasing salinity of the water, the reverse process takes place, resulting in ground waters richer in alkalis than before.

A second process of exchange of equal importance is the absorption of potassium by the colloid particles, a process which, in contrast to the above, is presumably a strictly irreversible reaction, and leads finally to increasing impoverishment in potassium, i.e. to the enlargement of the Na^+/K^+ ratio in the ground water.

Most of the sodium and potassium of all ground waters originate in the chlorides of sea water (Conway 1942). Even in water from plutonic rocks the quantity of alkalis which originate from the decomposition of these rocks is almost nil as compared to the alkalis of cyclic origin (Bond 1946).

According to Rankama and Sahama (1950), the ratio of Na^+/K^+ in igneous rocks is 1.09, in sea-water 27.84, and in argillaceous sediments 0.36. The ratio Na^+/K^+, therefore, always increases in the liquid and decreases in the solid absorption phase.

The ratio Cl^-/SO_4^{--} in sea water is about 7.2/1. (equivalent ratio 9.7/1.). At the low salinities prevailing in the waters of the humid zone of the earth, this ratio is usually changed beyond recognition in favour of SO_4^{--} (Sverdrup, Johnson and Fleming 1942), chiefly through human influence (p. 178). Under the conditions of our zone, the original ratio is clearly observed. The relative increase of SO_4^{--} is caused, in addition to human influences, by (a) dissolution of sedimentary calcium sulphates (solubility increases with increasing concentration of chlorides), (b) the oxidation of sulphur and sulphides by organic agents.

The decrease of SO_4^{--} below the above ratio is the result either of reducing influences (presence of carbohydrates) or of the precipitation of calcium sulphate, if its saturation point is surpassed.

The evaporation of original sea waters first causes the precipitation of calcium sulphate and then of sodium chloride. Such a differentiation results in a relative increase of Mg^{++} and K^+, and to a lesser degree also of the SO_4^{--}, in the remaining solution.

The ratio Cl^-/Br^- ("bromine number") plays a very important role in the elucidation of evaporation processes. It changes rapidly during the precipitation of sodium chlorides, and it is therefore possible to determine the actual degree of evaporation. In normal sea water the ratio is about 288:1, and only minute quantities of Br^- are contained in the precipitated sodium chloride. By the end of the precipitation of sodium chloride this ratio is decreased to about 34:1. For practical purposes it may be assumed that the bromine remains entirely with the chlorides of Ca^{++} and Mg^{++}, which will be of importance in our further enquiries.

An important phenomenon in the chemistry of ground water is the exchange of Ca^{++} with Mg^{++}. This exchange takes place, it seems, not only through colloids, but also by the replacement of Ca^{++} atoms by magnesium in the calcite lattice through the liberation of calcium ions (dolomitisation), especially under conditions of high salinity.

GEOCHEMISTRY OF GROUND WATERS OF NORTHERN AND CENTRAL ISRAEL

In the present work, as far as the material at hand permits, we have treated the hydrological and chemical data on the water of Northern and Central Israel in accordance with the following geographical-geological grouping, drawn up on the basis of our knowledge of local conditions and on geological literature, primarily the standard work of Blake and Goldschmidt (1947) (see also Blake 1928, 1936; Goldschmidt 1935/6; Hydrological Yearbook 1946/7; Irrigation Service 1947; and Loewengart 1927 and 1928a and b.)

Geographical-geological classification of North and Central Israel ground waters

I.   Ground waters in the Coastal Plain (Pleistocene).

   A)   Between the southern slope of the Carmel and Coordinate 140 (south of Rehovot).
   B)   South of this line, but including only the area in which precipitation exceeds 350 mm.
   C)   Dune water of Haifa Bay.

II.   Ground waters in various other areas and geological formations.

   A)   Senonian-Eocene ground water of the northern part of the country and the Acre-Nahariya plain, the hinterland of Haifa Bay and the western Valley of Jezreel.
   B)   Senonian-Eocene ground waters in the Ephraim Hills.
   C)   Cenomanian-Turonian ground waters from borings.
   D)   Cretaceous-Karst ground water of the Mediterranean littoral.
   E)   Lower Pleistocene ground waters of Haifa Bay.
   F)   Ground water of Saqia and similar formations.
   G)   Ground waters of eastern formations draining into the Jordan Valley.
      (1)   Waters in the basalt of Yavne'el.
      (2)   Waters of the eastern part of the Jezreel Valley (Eocene and basalt).
      (3)   Waters in the intermediate formations of the western Jezreel Valley.

III.   Ground waters rich in redissolved evaporates.

   A)   Perched water horizons in Senonian and Eocene formations.
   B)   Waters contributing to the Jordan basin and the Dead Sea.

(1) Waters of Lake Tiberias and its tributaries.
(2) The Beisan Springs.
(3) Composition of Dead Sea water as compared to its tributaries.

I. GROUND WATERS IN THE COASTAL PLAIN

The basic features of the ground water of the Coastal Plain have been described by the author (Loewengart 1927 and 1928) and later treated in detail from the geological and hydrological point of view by Goldschmidt (1935/6) and Blake and Goldschmidt (1947).

The layers in which the ground water circulates are of a thickness of 20 to 100 m. The permeability of the aquifer, which is composed of sandstone (kurkar) and sand sediments, is generally good.

Intercalated are muddy and sandy "terra rossa" sediments and layers of similar character deposited in local depressions. The larger part of the layers is of terrestrial and the smaller part of marine origin. The marine layers are mostly composed of clastic material which, because of its permeability, contains no connate water. This, however, does not apply to the aquiclude Saqia layers, the salt contents of which possibly affect the composition of the water of the aquifer which is in contact with them.

A description of the composition of the ground water of the Coastal Plain should include data on (a) the general level of salinity as measured by the content of chloride, the dominant anion in most ground waters which is generally taken as the index of salinity, and (b) the interrelationships of the various components.

a. Salinity

The Cl^- content of 210 samples of the northern part of the Coastal Plain (I–A in the foregoing list) (Halperin 1955) and of 27 analyses south of Coordinate 140, but within the humid zone (I–B), is shown in Table I:

TABLE I
Chloride content of waters of the Coastal Plain

Northern Coastal Plain		Southern Coastal Plain (Humid Zone)	
No. of analyses	Cl^- (mg/1.)	No. of analyses	Cl^- (mg/1.)
120	Below 100	1	Below 100
68	100–200	9	100–200
17	200–400	13	200–400
5	Above 400	4	Above 400
Total 210		27	
Mean Cl^-	130		270

These figures do not include analyses from the city of Tel Aviv, in which the salinity has been considerably increased through the encroachment of sea water. The increase of Cl^- towards the south appears to be rather marked from Table I.

In Table II we present data on various waters representing minimal amounts of Cl^- found in different regions:

<div align="center">

TABLE II

Waters with very low Cl^- content

</div>

Locality	Classification	Yearly precipitation (mm)	Moisture Factor	Cl^- (mg/l.)
Wadi Gaaton Springs	Cenomanian Karst (see p. 195)	800	+9.7 (Eilon)	30
Kabri Springs	Cenomanian Karst (see p. 195)	800	+9.7	25
Tel el Kadi Springs	Drainage area 500–2000 m above sea level	over 800	probably >+10	16
Haifa dune area	Pleistocene (I–C)	680	—12 (Haifa)	30
Hadera paper factory	Pleistocene coastal plain (I–A)	600		47
Hadassim B	Pleistocene coastal plain (I–A)	550		50
Ramat Gan well (Herzl Street)	Pleistocene coastal plain (I–A)	532	—19 (Tel Aviv)	45
Bat Yam dunes	Pleistocene coastal plain (I–A)			30
Rishon le Zion (Vatikim)	Pleistocene coastal plain (I–A)	518	—22 (Rehovot)	45
Migdal Ashkelon dunes	Pleistocene Southern coastal plain (I–B)	430	—20, +30	90

It is seen from Table II, as well as from Table III, showing the average Cl^- concentration in each of the three zones under discussion, that there is a strict parallelism between the rise of the quantity of chlorides and the decrease of precipitation and the moisture factor of Thorntwaite (Meigs 1952). Besides precipitation and moisture index, different permeabilities of the aquifers and different intakes by the surface have much influence upon the concentrations of chlorides, but these factors cannot be measured as easily (cf. the relative low concentrations in the dune areas).

<div align="center">

TABLE III

Relationship between average chlorides, precipitation and moisture index in three Coastal Plain areas

</div>

Zone	No. of samples	Average Cl^- (mg/l.)	Precipitation (mm)	Moisture index
Haifa dune area (I–C)	11	100	680	—12
Central Coastal Plain (Binyamina-Rehovot) (I–A)	210	130	500–600	—17 to —22
Coastal Plain south of Rehovot to Gaza area (I-B)	27	260	350–500	—25 to —35

Can the quantity of chlorides presented above be derived from the sea? The available figures for the precipitation of chlorides with rainwater are scanty. Menchicovsky (1924) (personal information by courtesy of Dr. D. H. Yaalon) measured the composition of rain falling in Tel Aviv and found it to contain about 35 mg Cl^-/l.,

decreasing to 10 mg/1. beyond a distance of 6 km from the sea. As an intake of 25–35% is generally calculated for the ground water, concentrations of 33–100 mg Cl^- would result therefrom if rain were taken as the only source of supply.

Zohari and Fahn (1952) measured the salt spray in the dunes of Mishmar Hayam during 24 hours at a distance of 350 meters from the sea and found a precipitation of 0.46 mg Cl^- in 14 hr on an area of 1/100 m² at a distance of 350 m from the sea. Taking this figure as a rough estimate only, a quantity of 27.5 g Cl^- per m² would result. At a precipitation of 600 1. rain per m² and an intake of 30% to the ground water, a final concentration of 150 mg of Cl^- per 1. would be the result.

No indication exists as to how the distribution of chlorides from the sea to the land is divided between rain and spray. The very important contribution of Conway (1942) to the problem of the cyclic origin of chlorides can be taken only for general guidance, as his calculations are based entirely on conditions in the humid zones of the earth. If we take his calculations for the decrease of Cl^- from the seacoast towards the continent (ibid, p. 136), even higher concentrations of chlorides in our ground waters would result.

b. Relationships among salt components

As regards the interrelationships of the various components, a comparison is made in the following between the composition of ground waters and that of sea water by means of five different values:

1. The ratio of $(K^+ + Na^+)/Cl^-$, or the "alkali number";
2. The Cl^-/Br^- ratio;
3. The Na^+/K^+ ratio;
4. The alkaline earth content (carbonate hardness);
5. The Cl^-/SO_4^{--} relationship.

1. *The $(K^+ + Na^+)/Cl^-$ ratio.*—We recall that the alkali-to-chloride ratio $[(Na^+ + K^+)/Cl^-]$ of sea water is 88:100, which (multiplied by 100) represents the "alkali number." An increase in the alkali number above that of sea water may have two causes:

1. Supply of alkali salts which are not halogens, i.e. in actual practice carbonates or sulphates.
2. Exchange of Ca^{++} and Mg^{++} by alkalis during percolation.

The following considerations force us to discard possibility (1):

Sodium sulphate and sodium carbonate are deposited outside very arid surroundings in such small quantities that they cannot have been originally in the ground water. Free H_2SO_4 and H_2CO_3 react with $CaCO_3$ and $MgCO_3$ (the main material of almost all layers).

The increase or decrease of the alkali number can thus be caused only by base exchange, which takes place under our conditions as follows:

1. Up to alkali number 100: Na^+ replaces Ca^{++} and Mg^{++} in their halogens.
2. Above 100: Alkalis replace Ca^{++} and Mg^{++} in their sulphates and part of their carbonates.

3. Above about 120: Alkalis replace Ca^{++} and Mg^{++} in remaining carbonates, thus producing waters which have high pH values.

TABLE IV

Distribution of Cl^- contents, alkaline-earths/alkali ratios and average alkali number in the Northern Coastal Plain (I–A)

No. of cases	Cl^- (mg/l.)	Mean $(Ca^{++} + Mg^{++})/(Na^+ + K^+)$	Mean alkali no.
32	Below 60	2.4	100
99	60–100	2.3	97.5
77	100–200	1.9	90
15	200–300	1.4	85
—	Above 300	—	75

Figure 1 shows the frequencies of all the alkali numbers in the main Coastal Plain area. The peak of frequencies is between 75 and 85 (Figure 1). The average (mean) alkali number, however, is 96, i.e. over the whole range two-thirds of the entire $(Ca^{++} + Mg^{++})$ bound to Cl^- are replaced by alkalis through base exchange. This is, of course, only a small fraction of the total quantities of $Ca^{++} + Mg^{++}$, which are present mostly in the form of bicarbonates (200–400 mg/l. $CaCO_3$ and $MgCO_3$).

The calculations of average alkali numbers for different salinities presented in Table IV indicate that with increasing Cl^- content the alkali number decreases. As the ratio $(Ca^{++} + Mg^{++})/(Na^+ + K^+)$ becomes smaller, more Ca^{++} and Mg^{++} are set free into the ground water from the base exchange in the percolated strata. At low Cl^- concentrations the alkaline earths in the ground water, mostly carbonates, prevail and replace and set free alkali into the ground water. The alkali, by replacing the alkaline earths even from the carbonates in the ground water as a result of an extreme degree of base exchange, produce waters with extremely high pH values, which in Haifa Bay may reach up to pH 10.2. The alkali number in these cases reaches 130 and hardness is down to 40 mg $CaCO_3$ per l.

South of Coordinate 140 (I-B) the average alkali number was found to be almost 114, and in the dune water of the Haifa Bay (I–C) 105.

The breakdown of the alkali-number figures for the southern part of the Coastal Plain (I–B) is shown below:

Alkali number	No. of samples
Below 95	5
95–105	2
105–120	10
Above 120	9

The increase of the alkali number in the southern zone is caused by the higher temperature of the water, which results in a higher solubility of the alkaline earth
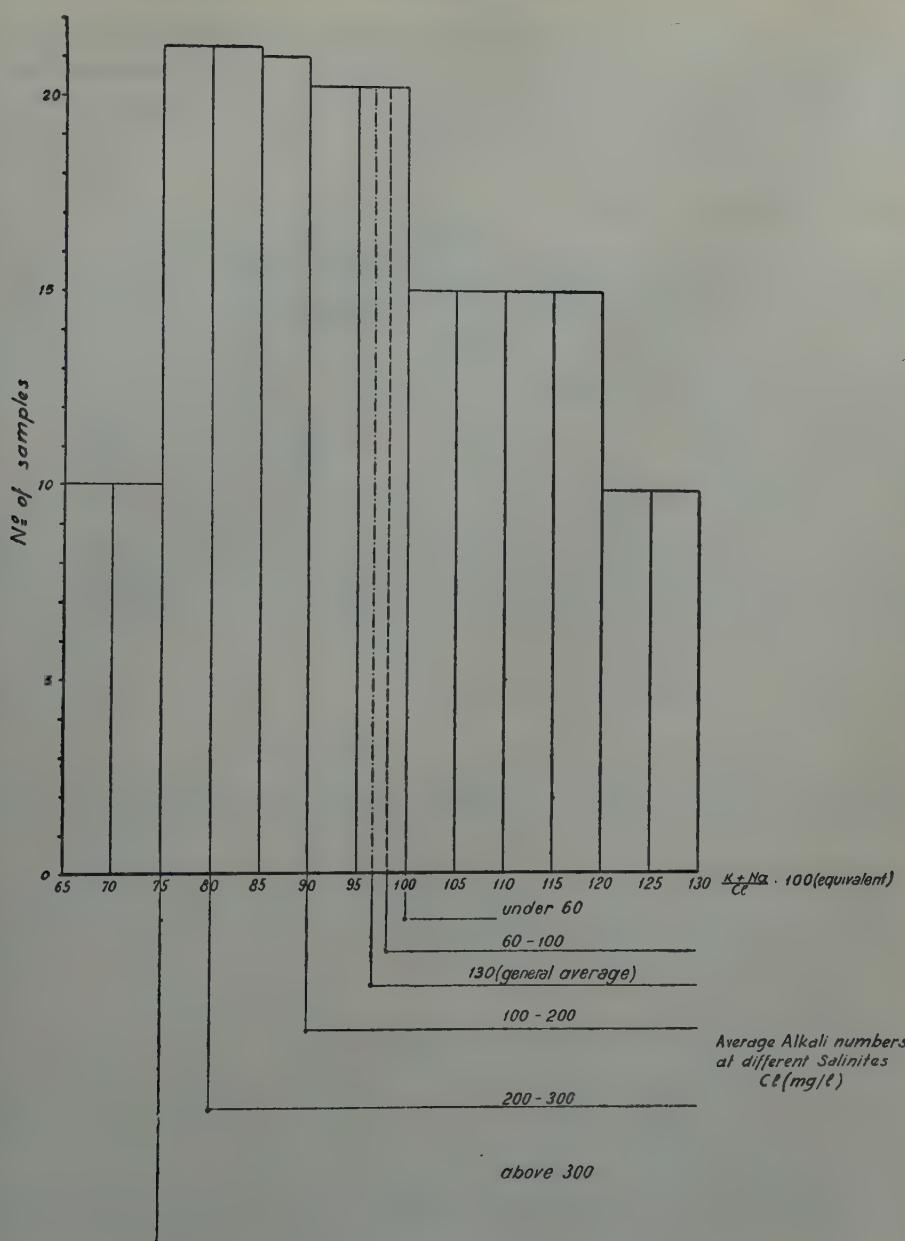
Figure 1
Main Coastal Plain ground water alkali number frequencies

carbonates. The presence of additional calcium sulphate (p. 190) also contributes to the increase of the $(Ca^{++} + Mg^{++})/(Na^+ + K^+)$ ratio and therefore leads to higher alkali numbers.

2. *The Cl⁻/Br⁻ ratio.* — The scant data available on the chloride and bromide in the Binyamina-Hadera area, given in Table V, show that the bromine numbers are almost the same as in sea water. Evaporation has never reached the stage where sea salts precipitate.

TABLE V

Bromine and alkali numbers of Binyamina waters

Site	Cl^- (mg/1.)	Bromine number	Alkali number
Binyamina			
New well, Shomroni	980	277	77.9
Ein Binyamin	422	288	65.8
Railway Station, Hadera	205	266	66.9

2. *The Na^+/K^+ ratio* (Figure 2).—As already explained, the ratio Na^+/K^+ must change in favour of Na^+ in the course of the cyclic motion of the water, infiltration, absorption by colloids and the biosphere, and back-flow into the sea water.
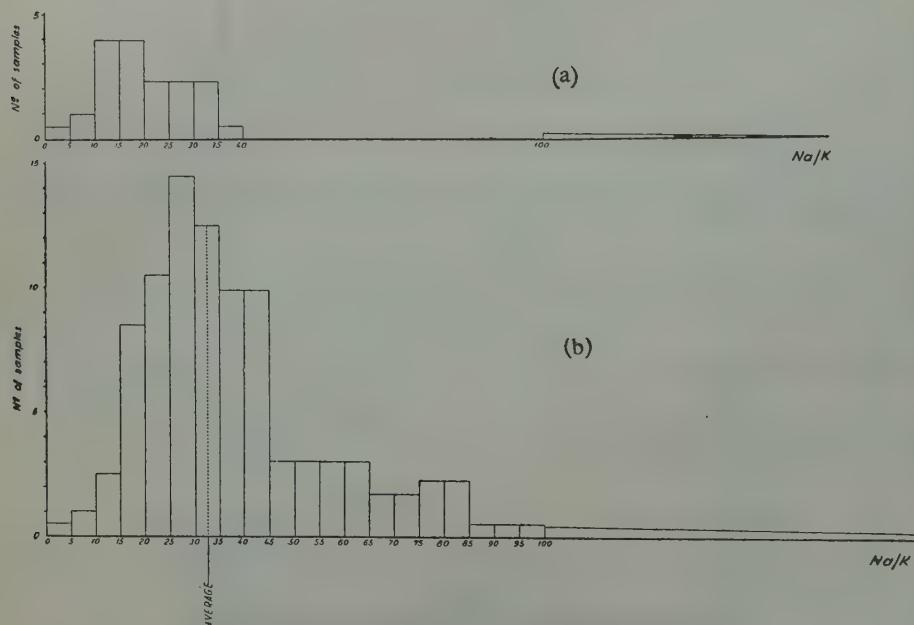

Figure 2

(a) Frequency of Na^+/K^+ ratios in ground waters of the Haifa Bay sand dunes
(b) Frequency of Na^+/K^+ ratios in the ground waters of the Central Coastal Plain (209 samples). In Na^+/K^+ ratios between 100–400 (4 samples) and above 400 (17 samples), no potassium could be traced

Because of the stronger absorption of the K^+ ions, any increase in the Na^+/K^+ ratio above 28:1 may be regarded as an anomaly. We may remark here that for an average content of 100 mg Cl^-/l. or 80 mg Na^+/l. the quantity of potassium is only 2–3 mg, so that this figure is significant only if a large number of analyses have been made.

Figure 2 shows the frequency distribution of Na^+/K^+ ratios among the main waters of the Haifa Bay and Coastal Plain.

Figure 2b shows that the peak of frequency (mode) in the Coastal Plain is similar to that of sea water (between 25 and 30). Forty-nine samples are below and 130 above this value. By excluding 1/5th of all figures on each side of the curve, the limit on the left side becomes 17.5, on the right side below 400. The harmonic mean of all these numbers gives an average for Na^+/K^+ of 33. The corresponding figures for Na^+/K^+ in the coastal plain south of coordinate 140 (I–B) (30 samples) is 52 and for the Haifa Bay (I–C) 18. The six figures for the Coastal Plain dunes area are excluded from Figure 2b, as they are regarded as exceptions for reasons which will be explained later, and are included with the figures for the dune areas in Haifa Bay presented in Figure 2a. The peak of frequency is here between 10 and 20, the median being at 18. The number of cases in Haifa Bay alone is of course too small to warrant any final conclusion. But there are also six cases from the dune area of the main Coastal Plain ground water with very low Na^+/K^+ ratios which support these data. How can this enrichment of K^+ be explained?

a. K^+ may become concentrated by evaporation. We have, however, excluded the possiblity of salts in the waters of the Coastal Plain resulting from evaporation (bromine numbers!)

b.   Artificial influence. This seems possible: K^+ may be concentrated locally from drainage waters, and we have found that waters of old Arab wells have unusually high concentrations of K^+. However this does not explain the fact that there are normal wells with high outputs and relatively low Na^+/K^+ values situated in the dune zone of the Coastal Plain.

c.   Velocity of ions. The explanation for the relative concentration of K^+ would seem to be the migration velocity of K^+-ions in relation to Na^+-ions (about 1.5 times higher) (Glasstone 1954, p. 895). Thus, when a solution of NaCl and KCl is superseded by pure water, the salts penetrate into the water at different velocities, and the proportions of NaCl are changed in favour of KCl. This may occur under various circumstances in the region under consideration, but the generality of the phenomenon can only be proved by testing ground waters at various sites along the coast in contact with solutions of sea water of known composition.

Comparing the average Na^+/K^+ ratio of 33 of the Coastal Plain to the corresponding 28 in sea water, we calculate that at least 18 percent of the K^+–content of cyclic salts are absorbed on the average before they reach the ground water.

We may compare the quantity of K^+ absorbed in the above process with the quantity of alkaline earths which are also absorbed in the layers above or within the

ground water. The average alkali number rises in the main Coastal Plain ground water from 88 (sea water) to 96, so about 10 per cent of the chloride is turned from $CaCl_2$ or $MgCl_2$ into NaCl. As the average content of Cl^- is about 130 mg/l. the equivalent of 13 mg Cl^- or about 7.5 mg/l. of Ca^{++} (i.e. not more than 5% of the total quantity present) or 4.5 mg/l. of Mg^{++} are absorbed during the process.

3. *The alkaline-earth content.* — It should be mentioned here that there exists a connection between the concentration of NaCl and the hardness of ground water expressed in p.p.m. $CaCO_3$ and $MgCO_3$ (Figure 3). By plotting Ca^{++} and Mg^{++} as $CaCO_3$ and $MgCO_3$ in mg per litre against mg Cl^- per litre for some 100 samples, we get the general pattern depicted in Figure 3, showing that an increase
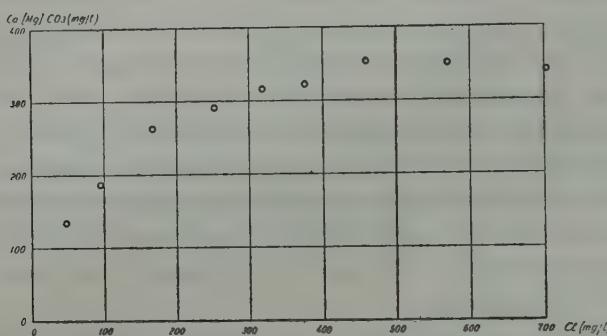

Figure 3

Increase of Ca(Mg)CO₃ hardness with salinity in ground waters of Northern and Central Israel

occurs, as known, in the solubility of alkaline earth carbonates with increasing quantities of strong electrolytes such as sodium chloride until a concentration of about 500 mg Cl^- per l. is reached.

It may be assumed that seasonal influences as well as slight seashore movements of the coastal zone both contribute to changes in the salinity of the ground water. A reduction in salinity from about 500 mg to 100 mg Cl^- causes the precipitation of about half of the content of carbonates. This process may explain the very quick hardening of sand deposits in the coastal plain, such as the ridges of kurkar sandstone of fossil dunes and the subfossil pectunculus sandstone on the seashore.

4. *The Cl^-/SO_4^{--} relationship.* — The figures for SO_4^{--} used in the present study were taken from the report of the Irrigation Service of the Palestine Mandatory Government, 1947 (ref. 16), and compared to the figures of Cl^- of the same analysis. These figures are not very meaningful when considered from the point of view of the Cl^-/SO_4^{--} relationship alone, but if it is assumed that all SO_4^{--} in excess of that expected on the basis of a Cl^-/SO_4^{--} ratio of 7.2 for sea water is of "non-cyclic origin", a very coherent picture emerges.

In Table VI, showing the Cl^- and SO^{--} values in the Central Coastal Plain, only one out of 30 samples shows a deficiency of SO_4^{--} as compared to sea-water (Binyamina). The quantity of non-cyclic SO_4^{--} in only one sample is more than 20 mg/l. (Maabarot) and in one more than 15 mg/l. (Beer Yaakov). The remaining 27 are under 10 mg/l. and their mean value is around 4 mg/l.

In the Haifa dune area (Table VII), 10 out of 11 samples show non-cyclic SO_4^{--} values ranging up to 25.3 mg/l., averaging 15 mg/l. We recognise here the influence of

TABLE VI

Cl^- and SO_4^{--} values in the central part of the Coastal Plain as compared to a Cl^-/SO_4^{--} ratio of 7.2 in sea-water*

Locality	Cl^- (mg/l.)	SO_4^{--} (mg/l.)	Non-cyclic SO_4^{--} (mg/l.)
Binyamina (Kellner)	86	5.0	−7
Hadera (Levitas)	80	11.9	0.9
Beit Yitzhak	103	15.0	1.0
Givat Haim	106	19.3	4.5
Maabarot	112	38.0	22.6
Iskandarun (Wadi Harari)	296	47.0	6.0
Tel Mond	60	16.8	8.4
Herzlia C	80	16.0	5.0
Herzlia C	38	9.8	4.6
Herzlia D	62	11.0	2.5
Kfar Shmaryahu	90	12.0	3.0
Magdiel (Eliashiv)	40	9.2	3.6
Magdiel (Hamarva C)	118	19.0	2.6
Magdiel (Hamarva D)	56	13.0	5.2
Jaffa Municipal Well	73	12.3	2.3
Khiriya	35	6.6	1.7
	32	9	5.4
Rishon Le Zion (Gan Moshe)	56	12.3	4.6
	60	15.0	6.6
	54	11.0	3.5
Sarafand-El Amar	64	18.0	9.2
	44	10.0	3.9
	44	10.0	3.9
Sarafand, Citrus Station	67	9.4	0.3
	68	14.8	5.6
	80	14.8	3.6
Yazur (Mikve Israel)	57	11.0	3.0
	60	12.0	3.7
Beer Yaakov	82	27.2	15.8
Rehovot Agric. Station	40	7.9	2.4

* The reader may remark the very low Cl^- figures in comparison to the former sections. The above measurements were taken in the thirties, and the general level of salinity has in the meantime increased considerably.

TABLE VII

Cl^- and SO_4^{--} values for the Haifa dune area $(I-C)$ as compared to a sea-water Cl^-/SO_4^{--} ratio of 7.2

Locality	Cl^- (mg/l.)	SO_4^{--} (mg/l.)	Non-cyclic SO_4^{--} (mg/l.)
Kiryat Motzkin	88	23	7.8
Silicate Factory	62	26	17.3
Industrial Zone	29	23	19.0
Sand Dunes Development Co.	90	29	16.6
Sand Dunes Test Wells	29	7	3
	59	8	0
	113	33	17.6
	178	12	–11
Railway Water Works	46	29	22.6
Kiryat Haim A	47	22	15.5
Kiryat Haim B	48	32	25.3

TABLE VIII

Cl^- and SO_4^{--} values for the southern part of the Coastal Plain $(I-B)$ as compared to a sea-water Cl^-/SO_4^{--} ratio of 7.2

Locality	Cl^- (mg/l.)	SO_4^{--} (mg/l.)	Non-cyclic SO_4^{--} (mg/l.)
Seida	116	33	17
Mejdel (Migdal)	352	82	51
Beer Tuvia	172	35	11
Ashkelon	44	53	47
Beth Affa (Negba) (average of 4 samples)	~370	~100	48
Gaza Municipality	112	30	15.8
Gaza (Tugfa Quarter))	260	86	50
Gaza (Railway Station)	120	27	11.4
Gaza (Jebelia)	152	32	11

the Haifa Oil Refinery, since considerable quantities of sulphuric acid enter the atmosphere and ultimately reach the ground water as sulphates (cf. p. 178).

The samples of the southern part of the Coastal Plain and the Gaza Strip (Table VIII) show a considerable increase in the quantity of non-cyclic SO_4^{--}. As there is no evident change in the sediments towards the south, the reason for the increase is to be sought in higher temperatures, smaller quantities of rain and lower moisture factors (cf. p. 182). Cyclic calcium sulphate is precipitated and redissolved in the ground water. The more soluble salts are constantly drained back into the sea with the ground water, while the calcium sulphate is kept back and becomes enriched in the coastal formation.

From all these facts the conclusion may be drawn that the chlorides and most of the sulphates of the Pleistocene ground water are of cyclic origin. The compositions

of the salts in the groundwater point to their origin from current transport through the atmosphere by rain, spray and wind. The averagc chlorine content of the ground water is at a level which may be reasonably explained by transportation through the atmosphere, taking into account that concentration takes place through evaporation of meteoric and ground water. Locally occurring higher concentrations of salts may be connate waters which, however, have not changed considerably or undergone evaporation to the point of crystallisation of sodium chloride.

II. GROUND WATERS IN VARIOUS OTHER AREAS AND GEOLOGICAL FORMATIONS

A. Senonian-Eocene formation ground water in the northern part of the country

This chapter comprises all analyses (Halperin 1955) from the north when the surface drainage is towards the Mediterranean. It includes wells of the Nahariya-Acre plain and part of Haifa Bay. They are classified as above, relying on Blake and Goldschmidt (1947), who prove that this formation is overlain only by a thin cover of Pleistocene deposits which form an aquifer of only secondary importance. Table IX presents the Cl$^-$ content and alkali numbers of these waters.

TABLE IX

Chloride content and alkali numbers of Senonian-Eocene ground waters

No. of cases	Cl$^-$ (mg/l.)	Alkali numbers	No. of cases
2	Below 100	Below 65	1
12	100–200	65–75	10
7	200–300	75–80	6
3	300–400	80–90	3
3	400–600	90–100	6
3	600–800	Above 100	1
2	Above 800		
Average	330	82	

There are two centres of high salt concentrations, one around Shavei Zion, Bustan Hagalil and Acre, and the second around Kurdani, Kiryat Bialik and Kfar Ata. Data for the first centre are presented in Table X and for the second in Table XI.

TABLE X

Salt values in high salt centres in the Acre region

Location	Cl$^-$ (mg/l.)	Na$^+$/K$^+$	Alkali number	Bromine number
Shavei Zion-Regba	646	100.0	76.5	—
Acre No. 14	1318	53.8	70.5	—
Acre No. 15	714	38.8	98.1	—
Acre Stud Farm	578	40.0	67.3	—

TABLE XI
Salt values in high salt centres in the Kiryat Bialik region

Location	Cl⁻ (mg/l.)	Na^+/K^+	Alkali number	Bromine number
Ata Factory	512	26.0	51.5	—
Kfar Bialik B	1046	36.0	77.0	266
Kfar Bialik C	702	39.8	81.0	—
Kurdani (Mekorot)	407	28.0	80.0	—
Kurdani Springs (for comparison)	656	54.0	82.0	256

The Na^+/K^+ ratios for the waters of this part of the country are shown in Table XII.

TABLE XII
Na^+/K^+ ratios in northern ground waters

No. of cases	Na^+/K^+ ratio
2	Below 10
2	10–20
2	20–25
3	30–35
6	35–40
1	40–50
4	50–70
2	100–200
5	200–400
5	Over 400

There are two wells (one Arab well in Acre and Bir el Krab at El Makr) which have a content of 53 mg K^+/litre, their Na^+/K^+ ratio being around 3. We believe that both wells are affected by infiltration of organic materials (both are shaft wells); a high concentration of K^+ is widespread among wells of this kind.

Bromine numbers of 269 and 281 have been recorded from the environs of Bethlehem-Waldheim. But we have also obtained bromine numbers with greater deviations from normal, such as Shavei Zion 220, Bassa 245 and El Makr 314 and 343. These numbers prove that the waters contain dissolved evaporate salts from the depths which may have ascended mainly along fault lines.

The Cl^-/SO_4^{--} relations, as in the Coastal Plain, are very closely similar to those of sea water, as may be seen from the following figures (Table XIII, compiled from the same source as before (ref. 15)).

The scarcity and slightness of deficits in SO_4^{--} point, as do some slightly lower bromine figures, to slight evaporations.

The origin of the salts may be explained thus:

1. By the inundations of sea water during the Pleistocene Age. At least a part of the Cretaceous land surface was not covered by an aquiclude like the Saqia beds in the south, and sea water was therefore trapped in the fissures of the Cretaceous limestone.

TABLE XIII

Cl^- and SO_4^{--} content of northern ground waters

Locality	Cl^- (mg/l.)	SO_4^{--} (mg/l.)	"Non-cyclic" SO_4^{--} (mg/l.)
Sidney Smith Camp (now Bustan Hagalil)	460	64	–4
Acre Stud Farm	66	13	3.8
Ein Sarah	58	18	10
Al Manshia, Acre	264	47	10
Kfar Hassidim (Tel Harbaj)	102	13	–1.2
Kfar Bialik A	488	69	1
Kfar Bialik B	604	83	6
Kfar Bialik C	376	43	9.5
El Mazar (Lind)*	340	50	3
El Mazar (Madi)*	204	32	3.7
Yagur B*	62	12	3.4
Yagur*	184	28	2.2

* These wells belong strictly speaking to section C (p. 194).

2. By the solution of evaporate salts which probably have come from older forma-tions or through air transport (spray) in the geological past from the zone of evaporation in the Jordan graben (cf. p. 198).

At least the second centre of high salt concentration was covered by the sea during the late Pleistocene. Bromine numbers here are only slightly different from those of normal sea water. The K^+ values are all very similar and point to relatively small losses by absorption; the concentration of salts in these waters probably increases with depth. The alkali numbers are relatively high in comparison with the high concentration of NaCl in these solutions, which may perhaps be explained by the absence of sufficient exchange minerals in the fissures of limestone which are the main aquifers. The lower alkali numbers and higher Na^+/K^+ proportions in the Acre-Shavei Zion area may be explained by a greater influence of evaporate salts, which, owing to their age, have lost their K^+-content through absorption during the geological ages, as we shall see also from the springs around Lake Tiberias.

B. Senonian-Eocene ground waters in the Ephraim Hills

The waters in this hill region have a relatively low Cl^- content, on the average much below 100 mg/l. The alkali numbers are at least partly very high, corresponding to a low hardness, influenced by the presence of basalts and basalt tuffs which have strong exchange capacities. The Na^+/K^+ proportions fluctuate widely. There are also waters with very low Na^+/K^+ ratios, e.g. from 3–10, as well as waters in which the K^+ is not present at all.

The three bromine numbers found in the analyses are 248, 260 and 311.

It would be very worthwhile to correlate the existing analyses with the geological profiles. The existing anomalies in the Na^+/K^+ ratios and bromine numbers point

to the probability that the small quantities of salt have their origin at least partly in evaporates.

C.   Cenomanian-Turonian ground waters.

Table XIV presents data on Cenomanian–Turonian borings.

TABLE XIV

Cl⁻ content of water from Cenomanian-Turonian borings

No. of samples	Cl^- (mg/l.)
9	Below 100
12	100–200
3	200–300
4	300–400
2	400–600

The average Cl^- content is 190 mg. The average alkali number is 87, corresponding fairly well to the alkali number of the Coastal Plain ground water at the same salinity.

In the vicinity of Zichron Yaakov are some wells with Na^+/K^+ ratios of around 5. All along the coast from Tantura to Zichron Yaakov, the bromine numbers are fairly normal (Ein Ghasal 290, Maayan Tzvi 277).

There are bromine numbers of 182 at Ginegar, 214 at Tel Adashim and similar figures from borings at Usha, Kfar Hassidim and Yagur. All these borings are probably in the neighbourhood of faults through which waters with evaporate salts may ascend.

In this zone, as in others previously mentioned, quite a number of waters show a high K^+ content and correspondingly low values for the Na^+/K^+ relation. Halperin (1955) mentions wells in the vicinity of Nesher in which K^+ is even in excess of Na^+. We discovered that all these wells were stagnant bore holes in which the K^+ collected from more or less impervious sediments, or were at least old-fashioned shaft wells with very low yields into which K^+ infiltrated from built-up areas.

Except for the coastal strip along Mt. Carmel, borings in which point to waters containing salts from recent and earlier inundations by the sea, all borings in the Cenomanian-Turonian contain cyclic salts of primary origin with admixtures of evaporate salts in small and medium quantities.

D.   Cretaceous-Karst ground water of the Mediterranean littoral

Data on the large natural outcrops of Karst water in the Cretaceous formations near the Mediterranean are presented in Table XV.

As regards the three northern springs (the first in the list), no doubt exists as to the purely cyclic origin of their salts. The small quantity of Cl^- leaves no room for additional Cl^- besides that of meteoric origin. The absolute quantities of K^+ are, in accordance with the very low salinity here, too low for detection.

The chloride of all samples with low salinity, including Ras el Ein, can be related to cyclic salts. Higher salinity cannot be explained only by cyclic transport, but must be regarded as residual from inundation by the sea in the geological past.

TABLE XV

Ground waters ("Karst waters") from Cretaceous formations of the Mediterranean littoral

Spring	Approximate yield (m³/sec)	Cl⁻ (mg/l.)	Na⁺ (mg/l.)	K⁺ (mg/l.)	Na⁺/K⁺	Alkali number	Bromine number	Non-cyclic SO_4^{--} (mg/l.)
Kabri	0.26	25	16			100		
Wadi Keren	0.2	28	15			84		
Wadi Gaaton	0.08	28	13			75		
Kurdani	1.5	656	355	6.5	54	82	256	−1.5*
Ein Saadah	0.3	1182	620	26.5	27.6	95		
Zerka (past Ein Safra)	0.2	230	120	2.25	57	88	282	18*
Zerka (at Roman Bridge)	2.3	1999	1175	56	26	92		
Ras el Ein	7.0	170	126	2.25	56	112		+18*

* Practically identical with the waters of the Naaman and Auja (Yarkon) rivers (ref. 16)

The difference in the ratios of Na^+/K^+ may be explained by the difference of the age of sea water admixed at the respective localities.

A lower K^+-content points to an older age of the infiltrating sea water, such as at Kurdani and Zerka (beyond Ein Safra), whereas the higher K^+-content for Ein Sada and Zerka (at Roman Bridge) points to a more recent inundation of sea water.

The alkali numbers, which are here almost identical with or above those of sea water, also point to the fact that water infiltrated directly from the sea without going through the process of base exchange.

The bromine number of Zerka (beyond Ein Safra) is almost identical with the bromine number of sea water and the bromine numbers of borings in the vicinity. The bromine number of Kurdani together with a slight deficiency of SO_4^{--} points to a small amount of evaporates, which are mixed with original sea water derived from inundation as described above. In contrast to all other springs enumerated in Table XV, the Ras el Ein waters have undergone considerable base exchange owing to the large distance between the points of infiltration to the location of the springs. Whereas the bromine number for the Ras el Ein (Rosh Haayin) Springs is not known, it can be assumed that the salts in these springs have cyclic origin. The increase in non-cyclic sulphate (18 mg) points to conditions in the drainage area of these springs being similar to those in the southern part of the coastal plain. This similarity is also reflected in the high alkali number and the K^+/Na^+ ratio, which are also identical with the corresponding figures of the Southern Coastal Plain (I–C).

E. Lower Pleistocene ground waters of the Haifa Bay

We omit a discussion of these waters, as the material available does not allow sufficient conclusions. We may mention here only their high salinity. In all probability the salts are of a connate origin, having undergone base exchange to a great extent.

F. Ground waters of Saqia and similar formations

About 14 analyses from this formation all show Cl^- values above 200 mg. They have high alkali numbers, most above 100, and may have undergone considerable base exchange. The Na^+/K^+ ratio is remarkable in the water of Irak Suweidan, which contains 1343 mg Cl^- and has a Na^+/K^+ ratio of 11. Wells at Ramle, Safaria and Faluja have Na^+/K^+ ratios of 5–15. We have at present no sufficient explanation for this phenomenon, and bromine numbers from these waters have so far been unavailable. The waters of this district should be compared with the geological profiles and also with the geophysical measurements. It seems at least possible that there exists a relationship between some highly saline waters and the gravity axis extending from Huleikat to Irak Suweidan. There may also be a relationship between the Na^+/K^+ ratio and structural features, as was found in the Los Angeles basin by Morse (1943). There is no doubt that the Saqia beds were laid down under similar anaerobic conditions as explained for the Senonian-Eocene formations (p. 197). This is proved also by the presence of pyrite, which gives rise to the exhalations of hydrogen sulphide emanating from this formation.

G. Ground waters of eastern formations draining into the Jordan Valley

1. *Waters in the basalt formations of the Yavne'el Valley* show a very low Cl^- content (below 100 mg), very little hardness and very high alkali numbers (from 160–285). This is explained, of course, by the high exchange capacity of the basalt tuffs and the basalt itself.

2. *Waters of the eastern part of the Jezreel Valley* (*Ein Harod, Beit Alpha*), from 12 borings, have an average chloride content of 320 mg/l. The Na^+/K^+ ratio is 45, being the average of six samples, the remaining six samples containing no K^+ at all. The average alkali number is 90, and the four available bromine numbers all lie between 260 and 270. The water probably originates from fissured Eocene and basalt. The lack of K^+ is caused by the richness of exchange materials contained in the basalts and the overlying Hamra. The origin of the salts is probably to be sought in the western part of the Jezreel Valley which contains beds with high salinity. The uniformity of the bromine number points to a uniform supply area, whilst the high Cl^- content excludes a purely cyclic origin of the salts.

3. *Waters in the intermediate formations of the western part of the Jezreel Valley* were collected in 8 borings, all the water coming from formations above the Eocene (Cenomanian waters of this district are included under "Cenomanian Waters," II–C). The boring at Pardess Hos, Affula, shows a peak value of 2220 mg Cl^-. All other values are below 300, the majority of them below 100 mg. The bromine numbers are between 250 and 308. These figures point to evaporation in the tertiary formations which consist of sweet water limestones, gypsum, clays and Hamra. According to this composition, the alkali numbers are relatively high.

III. GROUND WATERS RICH IN REDISSOLVED EVAPORATES

Having examined ground waters the main components of which are of meteoric and marine but not fossil origin and show little evidence of the existence of evaporates, it is necessary to consider the opposite group, consisting of the perched water horizon in the Senonian-Eocene of Galilee and waters draining into the Jordan depression and the Dead Sea.

A. Perched water horizon in Senonian-Eocene formations

A water horizon exists in this formation which results in numerous springs in all parts of Galilee. Quantitatively these springs are not very important, and the yield of the largest is only 35 litres/sec. All these springs, however, have one feature which it is very important to mention, i.e. with a Cl⁻ content below 100 mg, all have quite abnormal bromine numbers. The springs around Megiddo-Lajun have the lowest bromine numbers at 86. The largest spring, Ein Kastel, has a bromine number of 146, and all other bromine numbers are below 230. There exists only one higher bromine number, Ein Tivon—315 (figures from unpublished analyses which I owe to the courtesy of Dr. Bloch of the Dead Sea Works, Ltd.).

Regarding the conditions under which these sediments came into existence, we may suppose that sedimentation took place chiefly under anaerobic conditions. We are in agreement with Picard (1943) that such conditions prevailed in this geological age, and evaporations may have taken place in closed basins during that period.
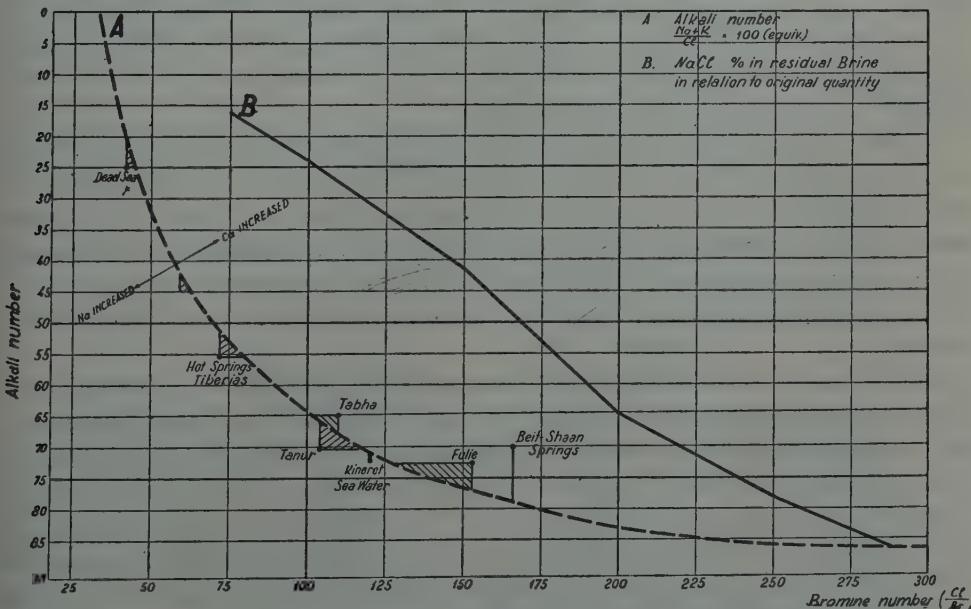
Figure 4
Relation between bromine number and alkali number

From Figure 4 we can obtain the degree of evaporation of sea water corresponding to a fixed bromine number, and we may ask what happened to the deposited sodium chloride absent from the corresponding residual brine. The residual brine is absorbed (trapped) according to the tectonic conditions laterally to the precipitated salts, which may not be preserved at all or be deposited at places where their detection may be impossible.

It is, however, not certain that the salts of this formation have a connate character. The evaporates with a low bromine number may have been transported by easterly winds from the Jordan valley at a later geological age as salt spray under conditions of a much more arid climate than that of the present.

B.   Waters contributing to the Jordan Basin and the Dead Sea

A considerable quantity of salts is contained in all the waters flowing into the Jordan Basin, and all these solutions become concentrated by evaporation in the Dead Sea.

It has always seemed a challenging undertaking to determine the source of this gigantic accumulation of salts. The author as far back as 1928 attempted to find reasonable explanations for the composition of the Dead Sea brine. Because of the many new publications since then and the new facts and figures of a hydrological and chemical nature which have accumulated, it may now be possible to solve many of the problems which have existed hitherto.

When examining the geochemistry of the waters of the Jordan Valley, we are limited to the waters inside Israel territory. We also exclude from the scope of this study waters originating north of Lake Tiberias, which are very poor in chlorides and soluble salts and relatively poor in carbonates, owing to the relatively low average temperature of the drainage area.

1.   *Waters of Lake Tiberias and its tributaries*. The figures reported from the springs and tributaries of the River Jordan entering Lake Tiberias give a Cl^- value of 26 mg/l., whilst the alkali number far exceeds 100, pointing to a situation in which the alkaline earths are far in excess of the alkalis, the $Ca(Mg)CO_3$ content being around 200 p.p.m.

The important springs which drain into Lake Tiberias are enumerated in Table XVI, the analyses having been taken from the sources referred to in the General Introduction.

From Figure 4b the conclusion may be drawn that the brine of the Tiberias Hot Springs is a residual one from which 85 per cent of the NaCl has been precipitated. For the average Lake Tiberias brine (bromine number 120) and the brine of the Beisan Springs, "precipitated NaCl" values of 70 and 50 per cent respectively may similarly be calculated from the data in Figure 4b. The Na^+/K^+ ratio in these solutions subsequent to the precipitation of NaCl was at the outset probably much more below the original ratio of 28:1 for sea water than the present-day figures would indicate. Thus, a loss by precipitation of 50 per cent of the NaCl of sea water would produce a ratio of 14:1 and of 85 per cent (as in the Tiberias Hot Springs) a ratio of about 4.8:1. The theoreti-

TABLE XVI
Salt content of tributary waters of the Jordan Basin rich in redissolved evaporates (from north to south)

Source	Cl^- (mg/l.)	Cl^-/Br^-	Alkali number	Na^+/K^+	Cl^-/SO_4^{--}	Yield (mill. m³ per year)
Jordan entering Lake						
Tiberias	23	280	160–180		4	560
Tabha	652	105	64.6	25.2	12.5	3.83
Tanur	1844	108	71.5	22.5	22.5	18.14
Tinah	112	441				2.9
Ein (Wadi) Amud	25					1.26
Rubadia	30	82–139				9.10
Mudawara	110	324				2.13
Humam	50					0.5
Fuliah 11	1432	143		20	8	—
Fuliah 4	360	415				—
Fuliah 5	913	155	73	27.3		—
	1187					
Tiberias Hot Springs	18800	73	57.1	19.7	25	1.0
Lake Tiberias	283	120	72.6	19	8	
Beisan Springs with high Br^- content (see p. 202)	770	166	70	74		68

cally expected Na^+/K^+ ratios obtained from calculations of this kind from the data in Figure 4 are listed in Column I of Table XVII. Subsequent absorption of K^+, however, caused a secondary rise in the ratios to the values actually existing today, as listed in Column II of Table XVII. By dividing the actual ratio of Column II by the corresponding ratio of Column I before the absorption of K^+, values ranging from approximately 2.2 to 5.2 are obtained, of which the reciprocals express the fraction of original K^+ still remaining in solution, i.e. some 30–40%.

TABLE XVII
Initial (calculated) and present Na^+/K^+ ratios for Jordan Basin tributary waters following precipitation of NaCl and secondary absorption of K^+

Spring	I Theoretical Na^+/K^+ following precipitation of NaCl	II Na^+/K^+ following secondary absorption of K^+	II/I*
Tiberias Hot Springs	4.8	20	4.16
Tanur	7.3	22.5	3.08
Tabgha	7.7	25.2	3.26
Fuliah 5	12.4	27.3	2.20
Lake Tiberias	7.3	19	2.60
Beisan	14	74	5.2

* Reciprocal of this value expresses fraction of original K^+ still preserved in solution

The disappearance of K^+ from a brine trapped in an aquifer for millions of years and partly exchanged for Na^+ and the alkaline earths is not improbable, and deposited quantities appear to be very modest in comparison to the general averages of K^+ contents of sediments. The absorption of K^+ from a brine having the concentration of the Tiberias Hot Springs in a container bed of about 50 per cent storage capacity would raise the percentage of deposited K^+ by 0.2 per cent only, the average content of K^+ in sandstone being around 1.5 per cent (Rankama and Sahama 1950).

With regard to the level of SO_4^{--} relatively high values result from the inflow of Jordan waters and probably other sources of run-offs into Lake Tiberias. By deducting all sources of surface water, the average for the SO_4^{--}/Cl^- may be placed somewhere around 1:12, which is the SO_4^{--}/Cl^- ratio of a marine brine before the precipitation of NaCl. (The original ratio is 1/7.2, about 1/3 of the SO_4^{--} becoming eliminated by precipitation of gypsum.)

The highest Cl^-/SO_4^{--} ratios are in the Tiberias Hot Springs and in Tanur, the waters of which smell extensively of H_2S; sulphates have been decreased by reducing agents.

All the springs around Lake Tiberias have a saline rather than volcanic character. The very remarkable coincidence of bromine numbers with alkali numbers shown in Figure 4, the very high strontium content and the deficiency of SO_4^{--} support this statement. As regards their radioactivity, sedimentary formations from which these springs derive may have a higher radioactivity than basic magmas (Rankama and Sahama, 1950, p. 784–85).

  a. *Geochemical balance of Lake Tiberias.*—The total inflow of water, Cl^- and Br^- into Lake Tiberias from all spring and river sources as far as their run-off is known, based on the foregoing figures, is shown in Table XVIII.

TABLE XVIII

Total yearly inflow of river and spring water, chlorides and bromides into Lake Tiberias

	Inflow (m³/year)	Cl⁻ (mg/l.)	Cl⁻ and Br⁻ (tons)
Waters from all springs with yield accounted for in Table XVI	38.8×10^6		
Waters from the Jordan River	560×10^6		
Cl⁻ from springs			65,000
Cl⁻ from the Jordan River		23	12,880
Total Cl⁻			77,880
Br⁻ from springs			662
Br⁻ from the Jordan River			40
Total Br⁻			702

Bromine number in water from the springs and Lake Tiberias	111
Total outflow of Cl⁻ from Lake Tiberias (tons)	144,500

Unaccounted for inflow of chlorides (with inflow
   and outflow considered to be in equilibrium)   66,700 tons, or 46.2%
Unaccounted for quantity of Br^- (tons)   502

Average bromine numbers are therefore: In accounted for springs: 98 (with Jordan 110); unlocated inflow: 130.

According to Neumann's (1953) estimate, the total yearly run-off into Lake Tiberias is 135×10^6 m³, which he divides as follows:

Springs 65×10^6 m³

Storm water inflow 20×10^6 m³

Storm water inflow into Jordan below Jacob's Daughters
    Bridge and underground inflow into lake 50×10^6 m³

The accounted and unaccounted for parts of the Lake Tiberias inflow have similar Cl^-/Br^- and Na^+/K^+ ratios, indicating that the salts of both derive from the same residual brine that has lost varying quantities of its sodium chloride by precipitation.

   b. Relation between alkali number and bromine number (see Figure 4).—All available material points to the fact that in halogenic brine the Br^- is the residual which runs entirely with the alkaline earths (Bloch and Schnerb 1953). Taking as a basis the original brine of the sea, the ratio Cl^-/Br^- of which is 288, we may assume, since geochemical literature indicates that no major changes have taken place in the relative concentrations of chlorides and bromides, that the halogens of Na^+ and K^+, constituting 88 per cent of the total halogens, contain practically no Br^-, whilst the remaining 12 per cent of the halogens, associated with the alkaline earths, contain all the Br^- when evaporation takes place. Thus, theoretically a marine brine after the precipitation of the NaCl should possess a bromine number of $(288 \times 12)/100 = 34$, a value which corresponds rather well with the actual number. (After precipitation of most of the NaCl, but while still retaining KCl, Mediterranean brine possesses a bromine number of 44 [Bloch and Schnerb 1953]). We have therefore plotted the bromine number against the alkali number on the basis of the assumption that a brine of halogen salts composed entirely of alkaline earth should have a bromine number of 34 (Figure 4).

Theoretically the bromine number can be calculated as follows: If n is the percentage of alkali earth halogens in the total halogens, then the alkali number $+ n = 100$. The theoretical value of the bromine number for a given n should be: Bromine number $= 34 \times 100/n$, as depicted in the graph.

We shall now compare this graph with the real figures and see whether it holds. The results are rather surprising. In low concentration brines and in solutions where the bromine number is not far from normal (say above 200), the correspondence is obscure, but in all other cases it can be recognised beyond any doubt.

Referring to the graph, we may acknowledge that for bromine numbers higher than 200, or even 150, the alkali number is not very indicative of evaporates. Where the curve runs very flat, the effect of base exchange (enrichment of alkaline earth) is most marked in the Beisan Springs, and becomes smaller towards the left, at Fuliah and at Tabha.

On the same figure (4b) we have plotted the bromine number against the evaporation rate in per cents of residual NaCl (the remainder having been precipitated).

2.   *The Beisan Springs*. We discuss here the springs of the Beisan district which were described by Yaron and Heitner (1952), while by adding the analyses of Halperin (1955) we are able to correlate the results from two sources. The Beisan district contains the springs of Sachne, Asi and Fawar with bromine numbers of 148, 162 and 172. South of these is a second cluster of similar springs represented by Ein Soda, Ein Bala and Ein Dugheim, with the same Br^- anomalies and with high salinity.

Between the first and the second group are the springs of Jemain and Jausak, which have a considerable yield but normal bromine numbers and a relatively low salinity. By compiling the data from all the springs we can group them into two entirely different classes, as seen in Table XIX.

TABLE XIX
Salt data of springs of Beisan district

	Yield (m³/sec)	Cl^- (mg/1.)	Na^+/K^+	Alkali number	Bromine number
Springs with high Cl^-/Br^- ratio	2.09	770	74	70	166
Springs with a normal Cl^-/Br^- ratio	1.22	176	72	94	257

There is only one small spring, Ein Mujadis, on the slope of Mt. Gilboa. This, as an exception, has a very low Cl^- content and a bromine number of 180, which does not entirely fit into the picture (see Yaron and Heitner 1952). But we must take into account that the yield of this spring is only 40 litres/sec, and the Cl^- content only 60 mg/litre. Cyclic salts in this vicinity must, of course, have the bromine number prevailing in the whole Jordan Valley, i.e. about 130. The same is true also for the waters in the boring of Beit Yoseph which come from the pebble horizon of the Jordan Valley, and the composition of which cannot of course differ from the waters of the Jordan. Another exception resulting in an abnormal bromine number mentioned by Yaron (1952) is Bir Tubis in the vicinity of Dobrat. This spring belongs to the category of springs of the perched Senonian-Eocene horizon and therefore fits harmoniously into our picture.

Waters with an almost normal bromine number probably contain admixtures of very small quantities of precipitated salts with a far larger quantity of salts of cyclic origin. Their alkali number is of the same order of magnitude as the waters of the Coastal Plain in the corresponding range of salinity. The alkali number of the Br^--rich

springs is slightly lower than the corresponding value in water of the same salinity in the Coastal Plain, but as can be seen from Figure 4, an alkali number of 78 would theoretically be expected in correspondence with their bromine number if there were no base exchange.

The springs around Lake Tiberias as well as the Br^--rich springs from the Beisan Springs contain evaporates of the type resulting from the evaporation of a sea brine.

As can be seen from Figure 4b, these residual brines would correspond in composition to a sea brine in which 85 per cent (Hot Springs, Tiberias) to 50 per cent (Beisan Springs) of NaCl have already been precipitated. Corresponding to this residual brine there must, of course, be a deposition of NaCl either in the Jordan graben or alongside it. Considering the facial development of the corresponding formations and the Picard Scheme (1943, p. 33), it is more probable that the salts are deposited in the Jordan graben or west of it. According to the last paper of Bloch and Schnerb (1953), the bromine number of NaCl of Mount Sdom is 6500, and this corresponds to a bromine number of 110–150 in the remaining solution. Without entering into the dicussion about the age of Mt. Sdom, it may be that the deposit of NaCl represented in this outcrop is only one of other similar deposits to be found in the region. Bloch proves conclusively the difference between the salt deposited in the Dead Sea and the salt of Mt. Sdom.

It is to be expected that borings penetrating into the older formations will encounter more highly concentrated solutions of chlorides with high bromide contents. The evaluation of the analyses thus obtained should be of extreme importance in the search for oil and water resources.

3. *The composition of Dead Sea water as compared to its tributaries.* Is it possible to explain the composition of the Dead Sea by the composition of the Lake Tiberias Springs and the springs of the Beisan Valley?

The bromine number of the main water supply of the Dead Sea, the Jordan, is around 120, whilst the bromine number of the Dead Sea is around 47. Taking this figure as a basis for calculation, about 3 times the quantity of Cl^- contained in the Dead Sea has been lost. In order to regain the original Cl^-/Br^- ratio of the waters draining into the Dead Sea, the missing Cl^- is supposed to be deposited on the bottom of the sea as NaCl.

By taking either the Na^+ quantity of the Jordan or the Br^- excess of the Dead Sea as a basis, we arrive at figures indicating that about 5 times the present quantity of NaCl contained in the sea must have been precipitated. The quantity in the sea is about 12×10^9 tons (Rankama and Sahama 1950, p. 282). The amount precipitated may therefore have a median thickness of 25 meters when spread all over the bottom of the sea.

By taking an original sea brine and not the Jordan River as the base of calculations, it is shown in Figure 4b that about 95% of the sodium chloride is missing in a brine which has attained the Br^- number of 47. In this way one arrives conservatively at a figure of 200×10^9 tons NaCl. Even this figure is an absolute

minimum arrived at without taking into account that the drainage of salts in the Jordan depression continues unabatedly.*

In the same way we can explain the enormous enrichment of K^+ in the Dead Sea. The Na^+/K^+ ratio in the Dead Sea is 5.8. As we have, however, reduced the Na^+ quantity by a factor of about 5 by assuming that NaCl is deposited on the bottom of the sea, the overall proportion of Na^+/K^+ is 28/1, which corresponds fairly well to a mixture of Jordan water with the Beisan Spring waters.

The anomalies in the Ca^{++}/Mg^{++} relation are easily explained. According to the analysis of Blake (1928), the Jordan waters south of Lake Tiberias contain 28 mg Mg^{++} and 48 mg Ca^{++} per litre. The Dead Sea contains about 22×10^9 tons of $MgCl_2$ but only 6×10^9 tons of $CaCl_2$. By taking the total quantity of Cl^- in the Dead Sea, including the Cl^- estimated from the above calculations, and taking into account that according to the composition of the Lake Tiberias water the quantity of SO_4^{--} corresponds to about 1/8 of the total quantity of Cl^-, we arrive at a quantity of about 9×10^9 tons of SO_4^{--} which have not reached the Dead Sea. These 9×10^9 tons of SO_4^{--} correspond to about 4×10^9 tons Ca^{++} which have been precipitated as gypsum in the Lisan formation. If $CaSO_4$ had not been deposited, therefore, the total quantity of $CaCl_2$ in the Dead Sea would be around 18×10^9 tons. The low quantity of Ca^{++} in comparison with Mg^{++} would seem to be most satisfactorily explained by this precipitation of all incoming sulphates by means of Ca^{++} ions.

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BOOK REVIEWS

GEOLOGIE SEDIMENTAIRE. LES SERIES MARINES, by Augustin Lombard, Masson et Cie, Paris, 1956, 724 pp., 180 figs., 13 plates, 11,000 Fr. fr.

The ultimate purpose of the author of this monumental work was probably to accumulate proofs and logical arguments in favour of his theory, namely, that a common factor exists in the evolutionary sequence of the several terms with their changing facies of different sedimentary series. This sequence is part of a more general sequence, the "general virtual series". According to the author, these sequences, as well as stratification, are mainly the outcome of the slow and universal flow of the materials forming marine sediments along the bottom of the sea. This flow follows the slope of the bottom and the law of gravity. The gradient of the slope is subject to changes not only on account of the process of sedimentation itself, but as a function of tectonic deformations. This effect of the gradient of the sea bottom and the influence of surface morphology on denudation as a producer of the materials for the sediments are the main links between tectonics and sedimentation.

This reviewer finds that the extremely detailed treatment of the whole field of sedimentation is no less interesting than the author's attempt at a theoretical synthesis. The book starts with a critical review of actualism, followed by a description of present-day sedimentation. The subsequent chapter deals with the genesis of marine series, with the methods of study of sediments, with the problems of stratification. Next comes the discussion of the concept of facies and an ample treatment of rhythmic sequences. Finally, the problem of the genesis of sedimentary series is taken up again, within the framework of the author's theories. A wealth of examples, described in detail, partly from the author's own experience in Western Europe and in the Eastern United States and partly taken from the literature, is one of the notable features of the work. A bibliography of about 1250 items, of which between one-third and one-half are not earlier than the year 1950, also takes into account some very important recent Russian literature.

On account of the immense amount of material offered, the book makes no easy reading; its study should be spread over some length of time. But everybody, whatever his specialty, will find it a rich source of information useful to him. If he is a field geologist, for example, he will profit from the methodological parts and from the descriptions of known series and often will be able to see in a new light some of his own observations. And if, like the reviewer, he is more interested in mineral deposits, he will find food for thought and new lines of approach to genetic and practical problems in the very ample treatment (25 pages) of coal bearing series of Europe, America and North Africa, the several pages on oxidic iron ores, on salt deposits and on phosphates and the paragraphs on the sulphide deposit of Meggen, on the gold series of the Witwatersrand, on rhythmic uranium deposition, and more generally on the different forms of sedimentation and sedimentary differentiation.

The plates are excellent, the numerous line-drawings of uniform style, and the printing and paper clear and restful.

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Head Mineral Engineering Department
Technion—Israel Institute of Technology, Haifa

INTRODUCTION TO PHYSICAL GEOLOGY, by Chester R. Longwell and Richard Foster Flint, John Wiley and Son, N. Y. (Lampan and Hall, London), 1955, pp. 432.

This book follows in principle the treatises on Physical Geology published now for many years by these Yale professors. This reviewer has always warmly recommended these textbooks to his students for their simple language and enthusiastic and vivid description, combined with well-chosen illustrations which awaken in the reader a spontaneous love for earth sciences.

The authors apparently wish to explain the natural processes in geology and physiography with a minimum of technical terms. Yet for the benefit of the student outside the United States and the American student going abroad, a few more widely-accepted expressions and concepts ought to be incorporated in the book.

Chapter 1. The Science of the Earth. The recent trend, influenced by petroleum exploration, to divide research into surface and subsurface work might be pointed out here (or in the final chapter), not however, without drawing attention to the danger which the student of geologically well-surveyed countries is involved in by neglecting his training in surface field research.

Chapter 2. A General View of the Earth. This chapter explains in an inspiring manner and plastic style the philosophical aspect of Known and Unknown, of Time and Space, of the overall reign of gravity, of the position of geology between formal and historical sciences. The evolution of scientific ideas and reasonings is here, as in the subsequent chapters, well and far more considered than in most other outlines on physical geology.

Chapter 3 (and/or 16). Materials of Earth's Crust (Sedimentary Rocks). A paragraph on the hardening process (diagenesis and lithification) from the soft sediment to the fossil rock—the elementary question of most students—should be added here or to Chapter 16. This is important since the latter chapter does not provide the reader with a proper chemico-physical comment on the terms compaction and cementation.

Chapter 4. Geologic Times. This chapter should include some reflections on the meaning of palaeogeography, a basic notion in Earth History.

Chapter 5. Igneous Geology. The introduction to this chapter is a most lively tale on the birth of the Paricutin volcano. It reveals immediately to the reader the dynamic site of the problem. Some space should be given here (or in Chapter 18 or 20) to the relationship between tectonic and magma, to magmatic differentiation, to significance of rock-clans (Pacific, Atlantic, etc.) and to migniatites.

Chapter 6. Weathering and Soils. In view of the importance of fossil soils for the interpretation of climate and history of former epochs, a world map on regional distribution of soils (similar to that in de Martonne's "Traite de Geographie Physique") would be a welcome addendum to the section "Climatic types of soil" (p. 98). Terra rossa, tschernoziom, etc., deserve no less mention than laterite, unproportionately extensively discussed in this section. We would also propose enriching this chapter with a few sentences on caliche and other duri-crusts and the role which capillary action plays in their formation.

Chapters 7, 8, 9. Mass-Wasting, Running of Water, Sculpture of Land. The paragraphs on these physiographic processes—always well presented in the author's former text-books—have now been further improved by various references on geotechnical (even silting) problems which would also have an appropriate place in the final chapter on applied geology.

Chapter 10. Ground Water. The elaborate discussion on ground water includes Darcy's work. We would thus suggest supplementing this chapter with a presentation on the Herzberg-Ghyben salt–fresh-water interface as one of the rare "laws" in defined geo-hydrology.

The paragraph "Water finding" is in our opinion treated too shortly and too generally. It deserves to be expanded and, with the paragraph "Petroleum exploration," incorporated in the final chapter "Geology in Industry". Methods of research, technical operations and terminology (trap, discovery well, reservoir bed, etc.) are employed in the exploration of both liquid mineral deposits, oil and water. Ground-water science embraces, on the other hand, specific terms and problems, such as ground-water gradient, cone of depression, and perched and main water table, which we missed in the book. Examples, hitherto exclusively brought from humid regions, should also be chosen from more arid regions.

Chapter 12.   Glaciers and Glaciation. Not directly belonging to glacial processes but connected with the climatic situation of the "glacial ages" are the enormous terrestrial deposits formed outside the periglacial belt ascribed in semiarid-arid regions to the *pluvial* period. This phenomenon of the Pleistocene is mostly neglected in books dealing with the principles of geology.

Chapter 13.   Wind Action and Arid Lands. Origin and character of ventifacts are broadly discussed in the book, but the terms barchan and more surprisingly adobe are omitted.

Chapter 14, 15.   The Sea: Submarine Geology, Waves, Currents and the Sculpture of Coasts. The student will be thankful for the clear presentation of these items, usually less comprehensively discussed in other introductory textbooks.

Chapter 19.   Earthquakes, the Earth Interior. Here a short description is given of seismic prospecting. As most geology students already miss elementary instruction in geophysics in relation to geology at the start of their university courses, a short, separate chapter (or sub-chapter to Economic Geology) under the heading "Applied Geophysics" is suggested.

Chapter 17 and 20.   Deformations of the Earth's Crust; Mountains and Geosynclines. Graeben or rift valleys are doubtless major structural features of the Earth's crust (overshadowing in some regions the realm of faulting). There is thus no justification for the exclusion of Graben and Horst structure in our compendium. The same is true concerning the omission of the terms symmetric plus asymmetric anticlines, Schuppen (or imbricated structure) and nappes as a substitute for thrust sheets, especially since in the latter case Argand's cross-section through the Alps is demonstrated. Shield is also more frequently cited than "continental plates". The swells (and basins) of these shields are of such regional dimensions (especially in the southern continents) that they deserve to be put on a par and discussed together with the "broad undulations" of the "stable interior" (p. 337, 338). We consider as a didactical improvement of the paragraph "Structure of Western North America" (p. 342) the addition of a geological E-W cross-section through that part of the country. We also believe in the great tutorial value of an E-W cross-section through the U.S. (similar to those reproduced in Lobeck's works). It might be best attached to the physical map of Plate I.

Appendices. The appendices contain rock and mineral identifications, elementary cartography and symbols. An extensive index closes the book.

Illustrations. Except for the unclear printing of the photographs in Figures 13–17 and Figures 17–24, the present edition is again distinguished by the high standard of its illustrations, especially in the instructive diagrams.

<div align="right">

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BULLETIN
OF THE RESEARCH COUNCIL
OF ISRAEL

Section G
GEO-SCIENCES

Bull. Res. Counc. of Israel. G. Geo-Sciences

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TO

VOLUME 7G

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4. JACKSON, F., 1930, *Thermodynamics*, 4th ed., Wiley, New York

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Corrigendum
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P. 116, L. 13. — For "invariant system" please read "univariate system".